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10 Microbiological Safety Issues of Fresh Melons

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10.1 INTRODUCTION

In the U.S., melons are widely available year round and represent an important dietary component. In 2001 annual per capita consumption was estimated to be

Mention of trade names or commercial products in this chapter is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

14.9, 11.2, and 2.1 pounds for watermelon, cantaloupe, and honeydew melons respectively [1]. The value of these commodities in 2003 was reported to be $346,022,000, $372,965,000, and $93,241,000, respectively [2]. In recent years fresh-cut melons have become increasingly popular with consumers and now account for a large and growing proportion of melon consumption.

For most consumers, melons represent a refreshing and healthy dessert or snack. However, for a small number of consumers, the situation is quite different; melon consumption has been a source of foodborne illness. At least 17 melon-related outbreaks involving hundreds of cases have been reported since 1990 [3–5]. Additional outbreaks ascribed to "multiple fruit" or "fresh-cut fruit" also may have been due to contamination of an unspecified melon component. While the largest melon-related outbreaks have been attributed to various salmonella serotypes, other human pathogens including *Escherichia coli* O157:H7, *Campylobacter jejuni*, and Norwalk-like virus also have been implicated [4].

Survival and growth of human pathogens including salmonella, *E. coli* O157:H7, and *Listeria monocytogenes* in melon flesh has been demonstrated [6–8]. Annous *et al.* [9] reported growth of *S.* Poona on cantaloupe rind at 20°C.

Salmonella outbreaks in 2000–2002 were traced by the U.S. Food and Drug Administration (FDA) to melons imported from Mexico [10]. On-farm investigations in Mexico conducted by the FDA concluded that "measures were not in place to minimize microbial contamination in growing, harvesting, packaging, and cooling of cantaloupe." Detection of *L. monocytogenes* in cut melons resulted in a recent product recall [11]. FDA surveys of imported and domestic produce have documented the presence of salmonella and shigella in cantaloupe [12,13]. The incidence of salmonella on imported cantaloupe (from Mexico, Costa Rica, and Guatemala) was 5.3% and on domestic cantaloupes was 2.6%. Shigella also was detected on these samples, an incidence of 2% on the imports and 0.9% on domestic melons. On October 28, 2002 the FDA issued an import alert on cantaloupes from Mexico, halting all such shipments. Subsequently, export of Mexican cantaloupes to the U.S. by a small number of grower/packers who met FDA safety criteria was resumed [10].

In this chapter some of the production and postharvest handling conditions that may contribute to microbial contamination of melons are examined. Studies of the efficacy of conventional washing practices in reducing the microbial load on melons are reviewed. Finally, current research results pointing to means of improving the efficacy of melon disinfection are examined.

10.2 MICROFLORA OF MELONS

Melons, especially cantaloupe, present a variety of surfaces to which microorganisms may bind. In cantaloupe the epidermal cell surface is ruptured with a meshwork of raised tissue (the net). This net consists of lenticels and phellum (cork) cells. These cells have hydrophobic suberized walls to reduce water loss and protect against pathogen ingress. Also imparting a hydrophobic nature to

the outer surface of cantaloupe is the cuticle composed of waxes and cutin that cover the epidermal cells [14].

The ability of pathogenic and spoilage-causing bacteria to adhere to surfaces of melons represents a food safety problem of great concern as well as a source of economic loss to the produce and fresh-cut industry. The mechanism of attachment of bacterial cells to plant surfaces has been studied most extensively for plant pathogens and symbionts [15,16]. The predominant class of organisms on cantaloupe and honeydew melon were aerobic mesophilic bacteria followed by lactic acid bacteria, Gram-negative bacteria, yeasts and molds, and *Pseudomonas* spp. [17]. The populations of each of the categories of microorganisms were found to be higher on cantaloupe than on honeydew, both for whole and fresh-cut melon. Differences in the populations of the native microflora on honeydew and cantaloupe melons are most likely due to the rougher surface of the cantaloupe compared to the relatively smooth surface of honeydew melon. The extensive raised netting on the surface of cantaloupe melon no doubt provides more microbial attachments sites and helps to protect attached microbes from being washed from the surface, and possibly from environmental stresses such as UV radiation and desiccation. In unwrapped and wrapped sliced watermelon, *Pseudomonas* spp., *E. coli*, *Enterobacter* spp., and micrococci comprised the predominant microflora [18].

10.2.1 Spoilage Organisms

The primary causative agents for microbial spoilage of melons are mostly yeasts and molds and, to a lesser extent, bacteria. Several studies have demonstrated the presence of enteric bacteria, including Enterobacteriaceae and Pseudomonadaceae, on whole and fresh-cut melons [17]. Microorganisms responsible for postharvest diseases are not necessarily dominant on the surface of sound fruits; they are abundant in the environment and can easily contaminate the melon surfaces. In a study conducted at the Eastern Regional Research Center, it was found that the spoilage organisms in fresh-cut melon were mostly yeasts and molds, *Pseudomonas* spp., and *Erwinia* spp. [19]. The level of these organisms in freshly prepared cut melons was very low but gradually increased during storage at 5 or 20°C.

10.2.2 Human Bacterial Pathogens

The ability of human bacterial pathogens to attach to melon surfaces [20] and their virulence characteristics must both be considered. Results of a study examining attachment of bacteria from a mixed cocktail containing multiple suspensions of individual strains of each genus (salmonella, *E. coli*, and *L. monocytogenes*) on the surface of cantaloupes stored at 4°C for up to 7 days showed that salmonella has the strongest attachment to the cantaloupe surface followed by *L. monocytogenes* and *E. coli*, either as individual strains or as a mixed cocktail [20]. The strength of attachment increased slightly for *E. coli* over the 7 days of storage, but decreased for *L. monocytogenes*. Efficacy of

sanitizer treatments applied to inoculated cantaloupes at 7 days postinoculation was greatly reduced for *L. monocytogenes* and *E. coli* but not for salmonella. Surface irregularities such as roughness, crevices, and pits have been shown to increase bacterial adherence by increasing cell attachment and reducing the ability to remove cells [21].

Salmonella is among the most frequently reported causes of foodborne outbreaks of gastroenteritis in the U.S. [22]. Salmonellosis has been steadily increasing as a public health problem in the U.S. since reporting began in 1943 [23]. Five multistate outbreaks of salmonellosis have been associated epidemiologically with cantaloupes. The first in 1990 involved *S.* Chester, which affected 245 individuals (two deaths) in 30 states [22]. The second in 1991 involved more than 400 laboratory-confirmed *S.* Poona infections and occurred in 23 states and Canada [22]. A 1997 outbreak associated with *S.* Saphra was reported (www.cdc.gov/mmwr/preview/mmwrhtml/mm5146a2.htm). The most recent outbreaks (2000, 2001, and 2002) were due to *S.* Poona [5]. Other melons including watermelon have been associated with outbreaks of foodborne illness [5,24–26]. The implication of these outbreaks is that improvements are needed at the farm level to limit or minimize contact of melons with sources of human pathogens, and at the packinghouse level in sanitizing and processing conditions.

Other human pathogens including *E. coli* O157:H7 and shigella are capable of growth on melon flesh [6,7]. A 1993 outbreak of foodborne illness was attributed to cantaloupe contaminated with *E. coli* O157:H7 (M. Diermayer, Oregon Health Division, Portland, OR, personal communication).

10.3 FACTORS CONTRIBUTING TO MELON CONTAMINATION

10.3.1 Preharvest and Harvest Conditions

Relatively little definitive information on sources of human pathogen contamination of melons is available. The FDA suggested that preharvest contamination of Mexican melons with human pathogens may have resulted from use of sewage-contaminated irrigation water [10]. Irrigation water, transported over long distances and distributed to farms through open and unprotected aqueducts and channels, may become contaminated by animal or human activity (Table 10.1). Other potential sources may be from feces of birds [28,29], reptiles [5], or other wildlife in fields, or exposure to airborne contamination. The latter scenario was demonstrated by Annous *et al.* [30] in studies conducted in an apple orchard in close proximity to a pasture. Animal production activity was observed by one of the authors within several miles of melon production locations in California and Mexico. However, the limits of airborne distribution and survival of human pathogens attached to aerosols has not been reported. Suslow [31] was unable to recover salmonella from more than 900 individual field-collected melons produced in different regions of California during 1999–2001. It may be that contamination events in some

TABLE 10.1
Potential Sources of Melon Contamination

Preharvest
Direct fecal contamination — human, birds, reptiles, insects, other wildlife
Indirect fecal contamination — irrigation water, dust from animal production
During harvest
Poor worker hygiene
Packing plant
Contaminated process water
Poor plant sanitation
Ineffective washing
Cross contamination during washing
Poor worker hygiene

locations are highly sporadic and localized, e.g., to individual melons with adhering avian feces or insect damage, a melon defect observed by one of the authors in a California packing shed. Duffy *et al.* [32] reported that salmonella isolates obtained from washed cantaloupes in Texas were most closely related to isolates obtained from equipment and irrigation water, but DNA fingerprinting did not conclusively establish relationships between contamination sources. Contamination of melons could occur during harvest if worker hygiene was deficient [10].

Research is needed to identify specific sources of preharvest contamination of melons and to develop guidelines and good agricultural practices (GAPs) that reduce the risk of contamination. Appropriate training of farm workers in personal hygiene and avoidance of behaviors that result in melon contamination is essential.

10.3.2 Postharvest Conditions

Gagliardi *et al.* [33] reported in most cases little change or an increase of indicator microorganisms (total and fecal coliforms and enterococci) on melons during washing in samples obtained at packing facilities in the Rio Grande River Valley of Texas. They attributed contamination to the management of primary wash tanks or hydrocoolers, e.g., use of contaminated river water, buildup of soil in tanks, and depletion of chlorine. The contamination of cantaloupes in Mexico may have been due to cooling and washing with contaminated water [10]. The potential for such contamination also exists in the U.S. One of the authors has observed melon processing operations in which cantaloupes were tightly packed in tanks containing chlorinated water, with minimal opportunities for agitation of the melons or mixing of the water, prior to fresh-cut processing. Under such conditions, rapid depletion of chlorine at the melon surface and survival of attached bacteria on contaminated melons might be expected with the possibility of cross contamination of other melons in the tank.

Other potential sources of postharvest sources of contamination include poor personal hygiene or work practices by workers (one of the authors observed the failure of packinghouse employees to wear gloves or hairnets while handling melons; another worker used his foot to move cantaloupes down a ramp from a receiving platform to a conveyor) and inadequate plant sanitation. Accumulation of debris from incoming melons was visible on the aforementioned ramp and conveyors. Conveyors and processing equipment must be cleaned and sanitized on a regular schedule with sufficient frequency so as not to allow debris to accumulate and microbial populations to build up on food contact surfaces.

Such deficiencies can be addressed by development and implementation of a hazard analysis critical control point (HACCP) plan and an effective cleaning and sanitation program, and adherence to good manufacturing practices (GMPs). Of equal importance is employee training in food safety. Such training should be appropriate to the employee's job and in the employee's native language.

10.3.3 Mode of Microbial Attachment to Melons

The external surface of cantaloupe melons is characterized by the presence of a net comprising porous lenticellar tissue on the epidermis [14]. Such tissue provides numerous attachment sites for microorganisms and also may shield attached cells from contact with cleaning or antimicrobial agents (Figure 10.1). Microbial attachment and the possibility of internalization may occur in the stem scar region. In contrast, honeydew melon and watermelon have a smooth surface that should be less favorable for attachment and protection of

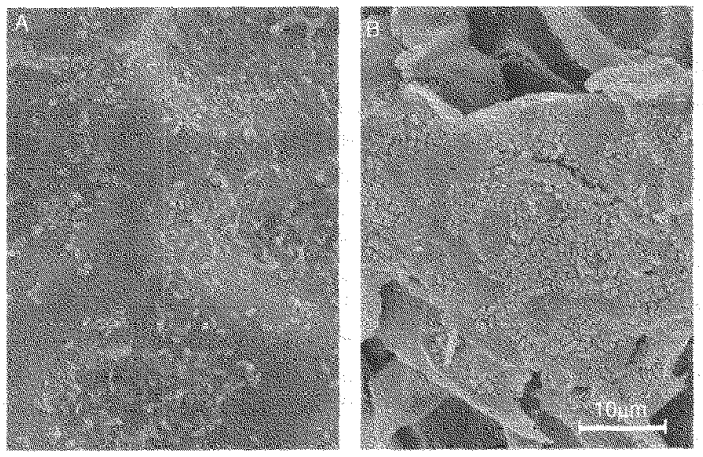

FIGURE 10.1 Scanning electron microscopy image showing bacteria on cantaloupe rind surface (A) and in lenticel (B).

microorganisms. Park and Beuchat [34] reported that greater numbers of *E. coli* O157:H7 and salmonella cells were inactivated or detached from inoculated honeydew melon than from cantaloupe when the melons were washed with sanitizer solutions. Similarly, the population of aerobic microorganisms on honeydew melon could be reduced to lower levels than the population on cantaloupes by washing with 200–2000 ppm chlorine solutions [35]. Similar results were reported by Ukuku and Fett [17].

10.4 EFFICACY OF CONVENTIONAL WASHING

10.4.1 WASHING IN THE PACKINGHOUSE

Field-packed melons are not generally washed because of the difficult logistics of supplying adequate water to mobile washing equipment. Melons transported to packing plants may be washed by spraying over rollers in flat-bed brush washers or by immersion in a wash tank [33]. However, these investigators found little or no reduction and in some cases an elevation in microbial populations on cantaloupes and honeydew melons washed with commercial equipment in packing plants in the Rio Grande Valley of Texas. This may have resulted from contamination of the wash water and/or depletion of chlorine by reaction with organic material. It also may have been due to the limited efficacy of brush washers in detaching microbial contaminants from melon surfaces. Annous *et al.* [36] demonstrated the inability of a flat-bed brush washer to reduce the population of *E. coli* on inoculated apples. In contrast, Materon [37] reported reductions of 3.2 logs in the populations of aerobic microorganisms on cantaloupes washed by unspecified means in four commercial packinghouses, also located in the Rio Grande Valley of Texas.

10.4.2 LABORATORY-SCALE WASHING STUDIES

Laboratory washing studies in which the melons are fully immersed in a sanitizing solution with scrubbing or agitation have demonstrated that significant reductions in microbial populations can be achieved. Ayhan *et al.* [35] reported reductions of 1 and 2 logs for the aerobic plate count on whole honeydew melons and cantaloupes, respectively, after dipping in 200 ppm chlorine (as sodium hypochlorite) solutions; reductions exceeding 3 logs were obtained on cantaloupes dipped in 1000 ppm chlorine. Park and Beuchat [34] compared 200 or 2000 ppm chlorine, 850 or 1200 ppm acidified sodium chlorite, 0.2 or 1.0% hydrogen peroxide, and 40 or 80 ppm peroxyacetic acid (Tsunami™) as sanitizers for cantaloupes inoculated with human pathogens. Population reductions of *E. coli* O157:H7 and salmonella cocktails approached or exceeded 3 logs for all of these treatments except hydrogen peroxide, which was less effective. Population reductions of total aerobic microorganisms were substantially smaller than reductions of human pathogen populations. Similar results were reported for honeydew melons.

TABLE 10.2
Effect of Postinoculation Storage at 5°C on Efficacy of Chlorine Wash in Inactivating Salmonella and Listeria and *E. coli* on Inoculated Cantaloupes

Bacteria	Days postinoculation	Survivors (log_{10} CFU/cm^2)[a]		
		Treatment[b]		
		Control	H_2O	Cl_2 (1000 ppm)
Salmonella[c]	0	4.6 ± 0.2	4.6 ± 0.1	1.5 ± 0.2
	3	4.7 ± 0.1	4.6 ± 0.2	2.0 ± 0.1
	5	4.6 ± 0.1	4.6 ± 0.1	2.4 ± 0.2
L. monocytogenes[d]	0	3.6 ± 0.2	3.1 ± 0.1	ND
	3	3.5 ± 0.2	3.3 ± 0.2	ND
	5	3.5 ± 0.2	3.3 ± 0.2	ND
E. coli 25922[e]	0	5.0 ± 0.1	4.5 ± 0.1	0.3 ± 0.1
	3	4.5 ± 0.2	4.0 ± 0.1	2.0 ± 0.1
	5	2.0 ± 0.1	2.2 ± 0.1	2.2 ± 0.1

Note: ND = not detected by plating.
[a] Values are means ± standard deviation of three experiments with duplicate determinations per experiment.
[b] Treatments applied for 3 min.
[c] Cocktail of *Salmonella* spp. containing *S.* Stanley H0558, *S.* Poona RM2350, and *S.* Saphra 97A3312. (Data from Ukuku and Fett [74].)
[d] Cocktail of *L. monocytogenes* containing strains Scott A., ATCC 15313, LM-4, and H7778. (Data from Ukuku and Fett [8].)
[e] Data from Ukuku *et al.* [41].

Sapers *et al.* [38] reported reductions in the aerobic plate count on cantaloupe surface of less than 1 log when rind plugs were washed by immersion in 1000 ppm chlorine, 1% APL KLEEN 246 (an acidic detergent formulation supplied by Cerexagri; www.cerexagri.com), or 4% trisodium phosphate. Immersion of whole cantaloupes freshly inoculated with *Salmonella* spp. in 1000 ppm chlorine solution for 5 minutes resulted in population reductions of 3 logs for salmonella [39,40]; however, the reduction was only 2 logs when the treatment was applied 5 days after inoculation (Table 10.2). With a nonpathogenic *E. coli* (ATCC 25922), the reduction was greater than 4 logs with freshly inoculated melons but less than 1.5 logs when the treatment was applied 72 hours after inoculation [41]. However, with *L. monocytogenes*, the time interval between inoculation and treatment had no effect on treatment efficacy [8].

Barak *et al.* [42] obtained a 1 log reduction in the population of *Pantoea agglomerans* (a surrogate for *S.* Poona) on inoculated cantaloupe by immersion in 150 ppm sodium hypochlorite for 20 seconds, followed by a 2-minute cold water rinse. In studies with cantaloupes inoculated with *E. coli* O157:H7, Materon [37] reported reductions generally exceeding 5 logs from washing by immersing the melons for 1 or 10 minutes in solutions containing 200 ppm

chlorine, 1.5% lactic acid, or 1.5% lactic acid + 1.5% hydrogen peroxide at 25 or 35°C. In view of the efficacy data obtained by other investigators, these extraordinary results are difficult to explain. It is possible that the recovery of attached bacteria from the melon surface by rubbing with a sponge was substantially less efficient than predicted by the investigator's validation procedure. Alternatively, the presence of residual lactic acid or hydrogen peroxide in the lowest dilutions plated may have been inhibitory to *E. coli* O157:H7 on Petrifilm™.

The FDA advises consumers to wash melons with cool tap water with scrubbing but without use of soap or detergents immediately before eating. Consumers are also advised to wash cutting boards, utensils, and counter tops often using hot soapy water followed by diluted bleach as a sanitizer. Avoidance of cross contamination with meat, poultry, or fish is essential (www.fda.gov/bbs/topics/ANSWERS/2002/ANS01167.html/). Fresh-cut processing studies conducted by one of the authors clearly demonstrated the need to develop and rigorously adhere to a strict protocol for sanitizing knives, cutting boards, and other food contact surfaces and equipment to avoid cross contamination and achieve an acceptable product shelf life. Attention to detail was found to be critical [38].

While the literature on efficacy of washing melons is limited and contradictory, the overall trend suggests that microbial populations attached to melon surfaces can be reduced by several logs if sanitizers are applied by immersion of melons in the solution with scrubbing and/or agitation. Treatment efficacy may be reduced if the time interval between contamination and washing is greater than one day, a likely situation with preharvest contamination. Since human pathogens transferred from the rind to the flesh are capable of growth on the flesh surface, the presence of even small numbers of survivors following a sanitizing wash represents a significant risk to consumers. Consequently, there is a great need for better methods of disinfecting melons so that this risk is minimized.

10.5 NOVEL DISINFECTION TREATMENTS

10.5.1 Hydrogen Peroxide

Hydrogen peroxide is classified as generally recognized as safe (GRAS) for use in food products [43]. It is used as a bleaching agent, oxidizing and reducing agent, and antimicrobial agent. The FDA specifies approved food uses of hydrogen peroxide such as treatment of milk used for cheese, preparation of modified whey, and production of thermophile-free starch. However, the FDA requires that the residual hydrogen peroxide be removed by physical or chemical means during processing. Hydrogen peroxide has not yet been approved by the FDA for washing fruits and vegetables. Antimicrobial activity of hydrogen peroxide as a preservative for fruits and vegetables [44], salad vegetables, berries, and fresh-cut melons [45] has been reported. Also it has been used to control postharvest decay in table grapes [46]. When used as a

TABLE 10.3
Population of *Salmonella* spp. on Cantaloupe Rind and Recovered from Fresh-Cut Pieces Before or After Washing Treatments and Fresh-Cut Preparation

Melon	Treatment	*Salmonella population*[a]			
		Log CFU/cm^2 *whole melon*	Log *reduction*	Log CFU/g *fresh-cut pieces*	Log *reduction*
Cantaloupe	Control	4.4 ± 0.1	—	2.1 ± 0.1	—
	Water	4.3 ± 0.2	0.1	2.1 ± 0.1	0.0
	H_2O_2 (2.5%)	1.9 ± 0.0	2.5	0.4 ± 0.1	1.7
	H_2O_2 (5%)	2.1 ± 0.1	2.3	0.3 ± 0.1	1.8
Honeydew	Control	3.1 ± 0.1		1.3 ± 0.1	—
	Water	2.7 ± 0.2	0.4	1.2 ± 0.1	0.1
	H_2O_2 (2.5%)	ND	~3.0	ND	~1.3
	H_2O_2 (5%)	ND	~3.0	ND	~1.3

Note: Cocktail of *Salmonella* spp. containing *S.* Stanley H0558, *S.* Poona RM2350, and *S.* Newport H1275 in the inoculum. Melons were completely submerged in bacterial inoculum (~20°C) for 10 min. ND = not detected by plating.
[a] Values are mean ± standard deviation of duplicate determinations from three experiments.
From Ukuku D.O., *Int. J. Food Microbiol.*, 95, 137, 2004.

sanitizer for whole melon surfaces at a concentration in the range 2.5 to 5% H_2O_2, there were significant ($p \leq 0.05$) reductions in the populations of inoculated *E. coli* and indigenous microflora [41] and approximately 2.3 to 2.6 and 3.0 log CFU/cm^2 reductions of salmonella on cantaloupe and honeydew melon, respectively (Table 10.3) [40,47]. Treatment of cantaloupes with 5% hydrogen peroxide at 70°C for 1 minute resulted in a 5.0 log reduction of total mesophilic aerobes, a 3 log reduction of yeasts and molds, and a 3.8 log reduction of inoculated salmonella [48]. When the initial level of salmonella on the melons was 1.9 log CFU/cm^2, no survivors were detected after treatment with 5% hydrogen peroxide at 70°C, even with enrichment. However, when the initial population on melon surfaces was at 3.5 log CFU/cm^2, the treated samples were negative for salmonella by plating but were positive upon enrichment.

10.5.2 Hot Water

Hot water decontamination of whole cantaloupes designated for fresh-cut processing was found to have major advantages over the use of sanitizers, including a significant reduction of microbiological populations on melon surfaces [48]. The major advantage was that it reduced the probability of potential transfer of pathogenic bacteria from the rind to the interior tissue during cutting. In experiments carried out in our laboratory, treatment of cantaloupes, inoculated with *S.* Poona, with hot water for 1 minute resulted in a 2.1 log reduction at 70°C and a 3.6 log reduction at 97°C (Table 10.4) [48].

TABLE 10.4
Inactivation of *E. coli* ATCC 25922 and *S.* Poona on Inoculated Cantaloupe by Surface Pasteurization With Hot Water for 2 min and Reduction of Transfer to Fresh-Cut Flesh

Experiment	Target organism	Treatment		Surviving population	
		Time (min)	Temp. (°C)	On melons (log_{10} CFU/cm^2)	On fresh-cut (log_{10} CFU/g)
A	*E. coli*	2	Control[a]	4.0 ± 0.6	—
			76	0.6 ± 0.6	—
			86	ND	—
			97	ND	—
B	*S.* Poona	1	Control	4.7 ± 0.1	2.9 ± 0.1
			70	2.6 ± 0.1	0.7 ± 0.1
			97	1.1 ± 0.2	—[b]

Note: ND = Not detected by plating.
[a] Untreated.
[b] Detectable by enrichment.
Experiment A data from Pilizota, V. and Sapers, G.M., Unpublished data, 2000; Experiment B data from Ukuku, D.O., Pilizota, V., and Sapers, G.M., *J. Food Prot.*, 67, 432, 2004.

Surviving *S.* Poona could not be detected by plating on fresh-cut pieces prepared from cantaloupes treated at 97°C but could be detected after enrichment, evidence that a small number of survivors were transferred during fresh-cut preparation. When the initial level of salmonella on the melons was 1.9 log CFU/cm^2, no survivors were detected after this treatment, even with enrichment, but with an initial population of 3.5 log CFU/cm^2, the treated samples were negative for salmonella by plating but were positive upon enrichment. Similar reductions in the population of salmonella occurred when treatments were applied to cantaloupes stored at 5°C for 5 days as for 3 days. In experiments with *E. coli*, the efficacy of hot water treatments at lower temperatures was compared with that at 96°C (Table 10.4). Surviving *E. coli* could be detected on inoculated cantaloupe by plating following treatment at 76°C; no survivors were detected at 86 or 97°C. These hot water treatments, which approach population reductions of 4 log CFU/cm^2, represent a substantial improvement over chlorinated water (1000 ppm) or hydrogen peroxide at ~20°C which yielded reductions of only 2 to 3.0 logs.

Additional information concerning hot water treatment of melons can be found in Chapter 21.

10.5.3 Steam

The use of steam to treat fruits is somewhat difficult to control due to time and exact temperature needed to maintain the desired texture. The application of steam on whole cantaloupe surface for reduction of microbial

population would be appropriate since melon has a thick rind that may protect the interior flesh from deleterious effects of the steam. In a preliminary study in our laboratory, steam pasteurization of melon surface was not promising compared to hot water treatment. The inability of the steam to reduce effectively total microbial populations on whole melon surfaces can be attributed to the surface roughness where the netting, cracks, and possible openings due to detached trichome can provide protection to the attached organisms.

10.5.4 Other

The application of an effective antibacterial agent to the surface of whole melons may be desirable. There are several reports that nisin, used in combination with a chelating agent, exhibits a bactericidal effect towards both Gram-positive and Gram-negative bacteria [49–53]. Treatment of whole and fresh-cut cantaloupe and honeydew melon with nisin-EDTA significantly reduced the natural microflora and extended the shelf life [17]. We also found that sodium lactate was inhibitory to the native microflora on melons [19]. The antimicrobial activity of lactic acid is due both to a lowering of pH and to disruption of the outer membrane of Gram-negative bacteria [54]. Application of lactic acid (2%) as an antimicrobial spray applied to animal carcasses to reduce surface populations of *E. coli* O157:H7 and salmonella has been reported [55]. Sorbic acid (pK_a of 4.76) and its potassium salt are widely used in foods at a concentration of 0.02 to 0.3% to inhibit yeasts and molds, but they also have antibacterial activity [56]. However, washing inoculated whole melons with sodium lactate (2%), potassium sorbate (0.02%), EDTA (0.2 M), or nisin (50 μg/ml), when tested individually, did not cause significant ($p > 0.05$) reductions in salmonella populations. Treatment of whole cantaloupe with nisin-EDTA may lead to both increased shelf life and a reduced risk of foodborne illness due to contamination with salmonella or other pathogens [17].

10.6 ISSUES WITH FRESH-CUT MELONS

The visual symptoms of deterioration of fresh-cut produce are flaccidity due to loss of water, changes in color resulting from oxidative browning at the cut surfaces, and microbial contamination [57]. Minimally processed fresh fruits and vegetables provide a good substrate for microbial growth [58,59]. Such substrate may allow proliferation of human pathogenic organisms like salmonella, *L. monocytogenes*, and enterotoxigenic *E. coli* that contaminate food when proper sanitation is not employed. Microbial spoilage of fresh-cut melons will depend on storage conditions and the initial microbial population of the melon. Honeydew melon generally has a lower initial microbial population than cantaloupe and also has been found to have a longer refrigerated shelf life [17,47]. Similar results were reported for minimally processed honeydew and cantaloupe melon stored at 4°C, and the authors concluded

that both the length of shelf life and type of spoilage were related to the type of fruit [60].

10.6.1 Transfer of Bacteria from Rind to Flesh

Fresh-cut pieces prepared from whole cantaloupe or honeydew melons showed the presence of mesophilic aerobic bacteria, Gram-negative bacteria, lactic acid bacteria, *Pseudomonas* spp., and yeasts and molds [17,47]. The predominant categories of microorganisms on fresh-cut cantaloupe immediately after fresh-cut preparation from unwashed whole melons were mesophilic aerobic bacteria and lactic acid bacteria. For fresh-cut honeydew, mesophilic aerobic bacteria predominated immediately after fresh-cut preparation. As days of refrigerated storage increased, other categories of microbes were detected in all samples, irrespective of initial treatment before fresh-cut preparation. The fact that the same categories of microorganisms were detected on fresh-cut pieces during storage as on the whole melon surface indicates that the microbes were transferred from the rind to the flesh during fresh-cut preparation. Transfer occurred during cutting and removal of melon rinds.

Salmonella inoculated on whole melon surfaces was recovered in fresh-cut pieces prepared from inoculated melons [39]. Similarly, Ukuku and Fett [8] reported survival and transfer of *L. monocytogenes* population from whole cantaloupe to fresh-cut pieces. The population on fresh-cut pieces also survived and increased during storage at an abusive temperature.

Ukuku *et al.* [48] reported that fresh-cut pieces prepared from cantaloupes inoculated with initial salmonella populations of 1.9, 3.5, or 4.6 log and treated with 97°C water or 5% hydrogen peroxide at 70°C were negative for salmonella by dilution plating, although positive by enrichment (Table 10.4). However, the populations of salmonella and all classes of native microflora in fresh-cut pieces prepared from sanitized melons were low compared to populations in fresh-cut pieces from untreated whole melon.

10.6.2 Outgrowth on Flesh

Populations of all groups of native microorganisms increased in fresh-cut samples as storage time increased, regardless of the treatment. The population of salmonella transferred from the untreated melons to the flesh during cutting averaged 2 log CFU/g for cantaloupe and 1.3 log CFU/g for honeydew. The population of salmonella on fresh-cut cantaloupe inoculated with 2.56 log CFU/g increased as storage time increased, especially at an abusive temperature [19,39] (Figure 10.1). Golden *et al.* [6] reported growth of salmonella inoculated directly onto fresh-cut cantaloupe, watermelon, and honeydew melons during storage at 23°C. Ukuku and Sapers [39] reported growth of *S.* Stanley on fresh-cut cantaloupe during storage at 8 and 20°C. Other investigators have reported that interior watermelon tissues support the growth of *Salmonella* spp. [7,61]. All melon-related foodborne outbreaks noted so far involved melons that were precut and held at unknown temperatures for some

period of time at restaurants and retail food stores prior to being purchased and consumed. The inner flesh of melons comprises mainly parenchyma cells containing sugars, organic acids, and other substances that may be released upon plant cell injury and support microbial growth. Tamplin [3] suggested that attention should be directed to cleaning the melons at the time of cutting, using clean and sanitized utensils and surfaces to minimize contamination of the edible portion, and immediately consuming or holding cut melon pieces at cold temperatures.

10.6.3 Suppression of Outgrowth

The application of effective antibacterial agents to the surface of fresh-cut melons may suppress outgrowth of the native microflora and any human pathogens. Studies showing antilisterial activity of nisin in TSB or PBS62, and demonstrating its activity against native microflora on whole and minimally processed cantaloupe have been reported [17]. However, total elimination of salmonella on the surface of whole or fresh-cut melon could not be achieved, probably due to surface irregularities and internalization which reduced the ability of antimicrobial treatments to contact or remove bacterial cells. However, treatment with the combinations sodium lactate–potassium sorbate or nisin–sodium lactate may lead to an increased shelf life and a reduced risk of foodborne illness from salmonella or other human pathogens; such treatments also appeared acceptable from a quality standpoint [17,63]. The use of nisin for treating fresh-cut melon may reduce the risk of *L. monocytogenes* outgrowth [64].

Bacteriophage was used to control growth and reduce population of *S.* Enteritidis on fresh-cut melons [65]. In our most recent study, we found that the native microflora of cantaloupe and honeydew melon was inhibitory to *L. monocytogenes* [66]. Lactic acid bacteria were used to improve microbial safety of minimally processed fruits and vegetables [67]. Other researchers have used antagonistic microorganisms isolated from the field to control postharvest pathogens and colonization of apple surfaces [68].

10.7 METHODOLOGY FOR MICROBIOLOGICAL EVALUATION OF MELONS

Accurate assessment of the microbiological quality and safety of melons requires use of suitable sampling, recovery, and detection methods that take into account the mode of attachment of microorganisms to the melon surface. This is especially important with cantaloupes because of their complex surface morphology characterized by netting and the presence of fissures, both of which are absent on honeydew melons [14,69]. The cantaloupe surface morphology provides numerous microbial attachment sites and opportunities for inaccessibility not present on other non-netted melons. However, all melons

will show variations in surface features that could affect microbial attachment and growth, especially in the stem scar and ground spot regions.

Beuchat and Scouten [70] conducted a detailed study of survival and recovery of *S.* Poona on spot- and dip-inoculated cantaloupes sampled at three sites: the intact rind, a wound, or the stem scar. Recovery was accomplished by stomaching excised rind in a wash solution containing 0.1% peptone, with or without added Tween 80, or by rubbing melons in the same wash solution within a plastic bag. They demonstrated the equivalence of a number of combinations of preenrichment broth, enrichment broth, and selective agar medium in detection of *S.* Poona recovered from the rind surface. They reported no difference in recovery of *S.* Poona from the three sites compared to when the inoculum was suspended in water or an organic matrix (horse serum); growth occurred in both spot- and dip-inoculated wounds over 24 hours at 21 and 37°C but not at 4°C. Addition of up to 1.0% Tween 80 to peptone may have enhanced detachment of *S.* Poona, recovered by the washing procedure. The stomaching and wash solution procedures appeared to give equivalent results.

Annous *et al.* [71] examined recovery and survival of *E. coli* NRRL B-766 on spot- and dip-inoculated cantaloupe rind. Less than 1% of the inoculum applied by spot inoculation to the rind surface could be recovered by excising plugs containing the inoculation sites and blending. *E. coli* survival on inoculated cantaloupe after treatment with 300 ppm chlorine or water at 60°C was greater if applied by dip inoculation of the melon surface compared to spot inoculation. The investigators compared two sampling methods for recovering bacteria from the melon rind surface: (1) excision and blending of 20 replicate plugs containing inoculation sites for spot inoculation or taken at random locations for dip inoculation, and (2) removal of the entire spot- or dip-inoculated rind with an electric peeler. With both methods, the rind samples were homogenized with peptone water, serially diluted, and plated. The methods were applied to melons inoculated with *E. coli* B-766 or *S.* Poona. A method was developed for calculating the melon surface area from measurements of the polar and equatorial diameters, based on an assumption that the cantaloupe was a sphere, oblate spheroid, or prolate spheroid. When expressed on an area basis, the population estimates for the two methods were the same with both test organisms (Table 10.5). Expression of the population estimate on a weight basis would be invalid, however, because of poor correlation between the rind weight and external surface area. The whole rind method is less time-consuming and requires less handling than the rind plug method.

Barak *et al.* [42] compared two elution methods with peeling and blending for recovery of *S.* Poona from inoculated cantaloupes. They reported better recovery with Butterfield's buffer containing Tween 80 as the eluant than with phosphate-buffered saline, similar recovery when agitation was provided by shaking or rolling, and better recovery by the elution methods than by peeling and blending. The last result was attributed to the release of inhibitory substances during blending.

TABLE 10.5
Comparison of Rind Plug and Whole Rind Sampling Methods for Recovery of *Salmonella* Poona RM 2350 from the Surface of Dip-Inoculated Cantaloupes

Storage of inoculated melon at 20°C (h)	*S.* Poona population[a] (log_{10} CFU/cm^2)	
	Plug method[b]	Whole rind method[c]
2	4.7	4.3
24	6.3	6.8
48	6.7	7.0
72	6.9	7.0

Note: Inoculum in water; population was 8.7 log10 CFU/ml. XLT-4 agar medium used to enumerate *S.* Poona cell densities.
[a] Mean for 3 melons per trial; no significant difference between plug and whole rind methods.
[b] Based on total cross-sectional area of 20 rind plugs, each with 20 mm diameter.
[c] Based on calculated surface area for spheroid or sphere.

Hammack *et al.* [72] compared methods for the recovery of salmonella from cantaloupes spot inoculated at levels to provide fractionally positive results. They obtained better recoveries by soaking in preenrichment broth as compared to rinsing with the broth, and by detecting the salmonella using a culture procedure. Such methods would be useful in evaluating melons subjected to antimicrobial treatments such as surface pasteurization in which surviving populations are very small or not detectable by ordinary plating.

10.8 RESEARCH NEEDS

While extensive research has been conducted in a number of areas relating to the microbiological safety and quality of melons, a number of gaps exist that impede further progress. One deficiency is the relatively small amount of information concerning melons other than cantaloupe. Another area requiring more attention is the nature of microbial attachment to melons, especially conditions favoring biofilm formation and internalization in the netting of cantaloupes and stem scar of melons. A better understanding of salmonella adhesion to cantaloupe is needed for the development of more effective washing treatments to control this organism on melon surfaces and fresh-cut pieces. With regard to sanitation methods for melons, the promising results obtained with hot water surface pasteurization should be extended to additional melons besides cantaloupe, and the possibility of adverse effects on quality and shelf life should be given further study. As a back-up strategy, research should be conducted on lower temperature surface treatments used in combination with other treatments that may be synergistic. Finally, because of the possibility of low-level survival of pathogens on melon surfaces

following such treatments and transfer to the flesh during fresh-cut processing, better means of suppressing outgrowth of survivors by treatment of fresh-cut melon with preservatives, irradiation, or other means should be investigated.

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